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(Vol. XVI., January, 1887.)

THE SIX-HUNDRED TON TESTING MACHINE AT THE WORKS OF THE UNION BRIDGE COMPANY AT ATHENS, PA.

By CHARLES MACDONALD, M. Am. Soc. C. E.

READ JANUARY 19TH, 1887.

WITH DISCUSSION.

A brief description of a testing machine capable of exerting a tensile strain of 1 200 000 pounds, recently constructed at the works of the Union Bridge Company, at Athens, Pa., and successfully applied in pulling to destruction a number of eye-bars of unusually large dimensions, may prove of interest.

In general it may be described as consisting of:—A Hydraulic Cylinder securely fastened between two longitudinal girders, which form the frame of the machine:—A Tail Block attached to the webs of the girders at convenient intervals:—and Two Connecting Blocks to receive the test pieces, attached respectively to the piston of the cylinder and the tail block: they are carried upon finished wheels, running upon an accurately lined and finished track resting upon the lower flanges of the girders. The strain upon the test piece is assumed to be equivalent to the hydraulic pressure upon the piston, which is measured by a Shaw mercury column and a spring gauge, both being referred to the center of the cylinder. The stretch is recorded upon a natural scale.

A reference to the drawings will indicate the details of this simple

piece of mechanism, and, it is hoped, furnish evidence of the accuracy of the methods by which important results have been obtained.

Inasmuch as the arrangements for applying compression strains have not yet been perfected, although they are in a forward state of preparation, your attention is directed to the machine as at present adapted to tensile strains only, reserving to the near future a presentation of the completed machine.

Plate I represents a general plan and elevation with sections. The cylinder is of cast-steel, 4 feet 3¾ inches diameter and 6 feet 0½ inch long, giving an effective area of 2 039 square inches, and a working stroke of 4 feet 11 inches. The maximum water pressure for which provision has been made is 600 pounds per square inch, which for a piston area of 2 039 inches produces a total strain upon the test piece of 1 223 400 pounds, under the assumption, which is believed permissible, that the resistance due to friction is sufficiently small to be neglected. For the purpose of facilitating observations, it was intended that the cylinder should have an effective area of exactly 2 000 square inches, so that one pound upon the gauges would indicate a ton of pressure, but a defect in the casting made a slight increase in the bore necessary. It is secured to the girders by steel bolts and angles, and the outer end is left open for inspection. The piston and rods are packed with ordinary packing, to be more fully described hereafter. The main girders are of wrought-iron, 60 feet long by 3 feet 5_8 inches high, built up of plates and angles rolled in one length. Holes are bored through the webs, 6½ inches diameter and 18 inches apart, for convenience of attachment of the tail block; along this portion of the webs the thickness of the metal is 2½ inches. They rest on, and are secured to, 12-inch cross-girders, which are bolted to masonry foundations. The top flanges are held in line by cast-iron brackets, *G*.

The tail block, *A*, is a steel casting, which may be attached to the girders, at intervals of eighteen inches, by two short steel pins on either side, 6½ inches in diameter, and any intermediate adjustment is obtained by four geared steel nuts, *C*, working on the rods, D^2. These nuts are turned by a central pinion on the shaft, *E*, the nuts, pinion and shaft being contained in the plate box, *F*.

The connecting block, B^2, is a slotted steel casting resting on wheels, and attached to the tail block, *A*, by four steel rods, D^2, 5⅛ inches in diameter, having the adjustment at *F* above described. Provision is made

for recoil by a steel rod, H, fastened to B^2, and passing through a brass friction-clamp, I, in the tail block. It will be observed that the rods, D^2, are held fast in the block, B^2, by double nuts, while they are free to push through the tail block, A. The effect of recoil at this end is therefore controlled by friction upon the rod H, and the amount of the friction required for that purpose is regulated by adjustment in the clamp I.

A vertical slot, disposed centrally between the rods D^2, admits the head of the eye-bar, which is secured by a pin passing through a pin-hole $7\frac{1}{2}$ inches diameter, and slotted $1\frac{1}{2}$ inches. When smaller pins are required, collars are added to fill. The object of this elongation of the pin-hole is to admit of recoil in the test piece itself—a no inconsiderable quantity in large bars. This recoil is taken upon a wooden block placed between the back of the slot and the end of the eye-bar.

The connecting block B, is similar in all respects to B^2, except in that it is attached to the piston by rods, D, of same size as D^2, the recoil in this instance being transmitted without injurious effect upon the piston.

Plate II is an enlarged view of cylinder head and piston, showing the copper-wire packing between head and barrel, also the piston and piston-rod packing, and the connection of cylinder with main girders.

Water is delivered from the pump through the pipe P, 3 inches diameter, and is discharged through the pipe P^1, of the same diameter, into a tank outside the building. The vertical distance from center of the cylinder to the surface of the water in this tank is 4 feet 6 inches.

Plate III illustrates on a still larger scale the detail of the piston packing. A sample of the packing itself is also submitted with the paper; it does not differ from that in general use, and is too well known to require description. This packing is "set up" by a brass gland and packing bolts, with thread and nut adjustment, until the leakage, under maximum pressure, is reduced to a thin film of water discharging uniformly about the periphery of the piston. After a test has been completed and the piston remains at a distance from the head of the cylinder equal to the stretch of the piece, it is brought back to a normal position by opening the discharge cock in the pipe P^2, and allowing the water to pass out under the head of 4 feet 6 inches, when it is found that the partial vacuum thus obtained, which is equivalent to 2 pounds per square inch upon the piston, is sufficient for the purpose. This is

equal to about four thousand pounds total pressure, and inasmuch as the pressure upon the packing, when properly adjusted by its gland for a maximum water pressure, is believed to be a constant quantity, it is assumed that four thousand pounds represents the maximum reduction which should be made as compensation for frictional resistance. This is scarcely one-third of one per cent. of the highest strain indicated by the gauges, and for all practical purposes it may be disregarded.

Pressure is supplied in the cylinder by a pump having three single-acting plungers, 2¼ inches diameter and 10-inch stroke, working at slow speed, and giving steady and uniform movement to the piston. An engine having one cylinder, 8 inches diameter by 8 inches stroke, is sufficient to work the pumps with such regularity that little or no fluctuation is noticeable in the gauges.

In operating the machine, the tail block, *A*, is attached to the web of the girders at the nearest range of holes corresponding to the length of test piece; the block B^2 is adjusted to exact position by the spindle *E*. The test piece is lowered into the slots by an overhanging traveler, and when the connnecting pins are driven the pressure may be applied. Upon starting the pumps the gauges begin to rise at a uniform rate, and continue until, for a moment, they cease to move, which fact is assumed as indicating permanent set. After this limit is passed the advance is at a gradually decreasing rate until the ultimate or highest pressure is reached; at this point they remain stationary, or with very slight vibrations, often for a considerable time, the stretch in the piece meantime continuing with increasing rapidity. When the stage of actual rupture is initiated the gauges begin to fall, slowly at first, afterwards with rapidly increasing rate, until the piece is broken. In order to prevent injury to the gauges by the sudden reduction of pressure at this instant, small check valves are placed in the supply pipes just under the gauges. They are light, and close by gravity, allowing the pressure to be relieved gradually.

The effective length of the cylinder being, as already stated, 4 feet 11 inches, it is possible to stretch a specimen to that limit before withdrawing the pressure in order to set back the tail block. This represents 12 per cent. stretch for an eye-bar 40 feet long, which is the limit of the machine, and for a great majority of cases this range is in excess of the ultimate stretch.

Under the maximum pressure for which the machine has been de-

signed, the principal members are subjected to initial strains up to the following limits:

Main girders.....	7 100	pounds	compression	per square inch.
Steel castings	15 000	"	"	"
" "	13 000	"	tension	"
" connecting rods.	15 000	"	"	"
" bolts	12 000	"	shear	"

All strains are referred to the net or effective sections, and this margin of safety appears to be sufficient to provide against injury from the sudden release of strain at the moment of rupture of test piece.

A fragment of a steel bar, 8 by 2¼ inches section, which has been tested to rupture on this machine is exhibited herewith; upon it will be found a full record of the test, in regular form, as follows—on page 6.

The maximum strain applied was 1 187 050 pounds, or 66 539 pounds per square inch on original area of 17.84 square inches. The remaining portion of this bar has been sent to Mr. B. Baker, M. Inst. C. E., in London, as a specimen of the material and workmanship for the Hawkesbury Bridge, for which tests were required.

Numbers of bars, ranging in section from 5 to 18 square inches, have been tested with similar results, and without the slightest injurious effect upon the machine. The specimen above referred to represents the largest bar thus far strained to rupture. The material was open-hearth steel, specified to stand 67 000 to 74 000 pounds per square inch on small specimens, ¾-inch diameter. Two steel bars, 8 by 2⅞ inches in section, have been strained up to 1 223 760 pounds without causing rupture, when it was thought prudent to discontinue the tests.

It has been previously stated that, at the moment of rupture a considerable reduction of strain is indicated by the gauges. A few observations of this reduction have been made; and, as a matter of interest, it may be stated that, in the case of the fragment exhibited, the strain per square inch at the moment of fracture, referred to the original area, was 57 464 pounds per square inch, as against 66 445 pounds maximum indication before final reduction began. If the area at point of fracture be considered, the actual strain upon that area was 118 867 pounds per square inch.

Your attention is called to the flow of metal at the zone of fracture, to the elongation of pin-hole, and in fact to the general appearance of the fragment as a whole, indicating, as it does, far better than any mere verbal description, the capacity of the machine.

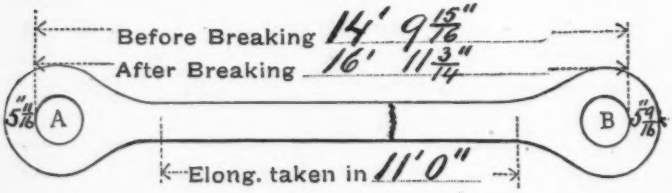
WORKS:
ATHENS, PA.
Late Kellogg & Maurice.
Capacity, 14,000 tons.
BUFFALO, N. Y.
Late Cent'l Bridge W'ks,
Capacity, 12,000 tons.

UNION BRIDGE COMPANY,
CIVIL ENGINEERS AND CONSTRUCTORS OF BRIDGES,
NEW YORK OFFICE, 18 BROADWAY.

Test No. 26.
Contract No.....
Original Mark, U.

TESTING DEPARTMENT,
AT ATHENS, PA.
November 1, 1886.

Full-sized test of Hawkesbury Bridge Steel Eye Bar, rolled by Steel Company of Scotland. Manufactured by Buffalo Shop, Union Bridge Company.



Head: Dimensions, $18\frac{3}{16}$ x 2.25 in.
Excess, 40.8 per cent.

Head: Dimensions, 18 x 2.18 in.
Excess, 34.1 per cent.

Diameter of pin-hole, 7.02 in.
Elongation of pin-hole, 1.25 in.
Nominal section, 8 x $2\frac{1}{4}$ in.

Diameter of pin-hole, 7.02 in.
Elongation of pin-hole, 1.76 in.
Actual section, 8.0 x 2.23 in.

Original area, 17.84 sq. in. Fractured area, 6.52 in. x 1.63 in. = 10.6270 sq. in.

Gauge reading for elastic limit.....297 = 605 765 pounds.
" " ultimate strength, 582 = 1 187 050 "

Elongation in 12 in., $3\frac{3}{8}$ in.

Elongation in 11 ft. 0 in., 1 ft. $9\frac{5}{16}$ in.

Elastic limit.....33 955 pounds per square inch.
Ultimate strength.....66 539 " "
Elongation in 12 inches.....28.12 per cent.
" 11 feet..... .....16.14 "
Reduction of area at fracture..... = 40.42 "
Fracture 75 per cent. fine crystal, balance fibrous.

REMARKS.

Eleven spaces of 12 inches each, elongated as follows:

(A) 2 ft. $0\frac{15}{16}$ in. + 1 ft. $1\frac{11}{16}$ in. + 1 ft. $1\frac{15}{16}$ in. + 1 ft. $1\frac{1}{16}$ in. + 1 ft. $1\frac{3}{16}$ in. + 1 ft. $2\frac{1}{16}$ in. + 1 ft. $3\frac{3}{8}$ in. fracture + 1 ft. $2\frac{5}{16}$ in. + 1 ft. $1\frac{9}{16}$ in. + 1 ft. $1\frac{1}{2}$ in. + 1 ft. $1\frac{1}{2}$ in. + 1 ft. $1\frac{7}{8}$ in.

UNION BRIDGE COMPANY,
By MILLARD HUNSIKER, *Inspector.*

At the present writing its sphere of usefulness is limited to the testing of tension members, not exceeding 40 feet in length, to a maximum strain of 1 200 000 pounds. The largest pin-hole provided for eye-bars is 7½ inches diameter, but flats, rounds and squares can be tested without pins by a simple attachment to the connecting blocks. When the plans for applying compressive strains are perfected, it will be possible to test specimens up to 32 feet in length and 800 000 pounds pressure.

The machine was designed by Mr. Charles Kellogg, M. Am. Soc. C. E. The late Mr. J. L. Marsh rendered valuable service to Mr. Kellogg in the preparation of plans and in superintending the construction. His death occurred immediately after its completion.

It is not contended that this is an instrument of precision, as for experimental research, or that in sensitiveness or minute accuracy it is the equal of the United States testing machine at Watertown Arsenal. Mr. Kellogg himself would be the last person to invite comparison in that respect with the invention of Mr. A. H. Emery. What he has accomplished has been the construction of a machine, at moderate cost, which will test to destruction full sized sections, as they are required for structural purposes, with rapidity and reasonable accuracy, of which the records submitted are sufficient evidence.

In reply to an inquiry regarding the Watertown machine, the writer has been favored with the following information by F. H. Parker, Major Ordnance Department U. S. A.

"A description and account of the machine is published in the Annual Report of the Chief of Ordnance, U. S. A., for 1883. From that you will see that the capacity of the machine is 800 000 pounds for tension tests and 1 000 000 pounds for compression. In the combination of the qualities of capacity, accuracy, sensitiveness, and convenience of manipulation, it is believed to stand alone, and precautions have been taken to prevent injury by recoil or reaction.

"The machine is continually operated, not only in testing large members of structures, but also small hand specimens where the greatest accuracy is desired; and it is necessary to use it in such a manner as will in no degree impair this latter quality.

"The machine has frequently broken bars to nearly its full capacity; but, in view of the constant demands made for accurate work in testing cannon metal, and in making tests for industrial purposes, it is not

thought advisable to run any risks of injury or delay by breaking bars of great length and large cross-section combined. The testing of such bars is carried far enough to give, probably, all useful information required.

"Government work on the machine occupies a great deal of the time; but considerable work for private parties is done."

From all of which it would appear that the magnificent piece of mechanism from which we had hoped to derive such valuable information; which was so admirably described by the late A. L. Holley, M. Am. Soc. C. E., in a paper read before the Institute of Mining Engineers, Vol VII, 1879, and for which not a few of our Members devoted valuable time and "influence" at Washington in quest of an "appropriation," is, in all probability, destined to occupy an honorary position in engineering science, and will be quite beyond the reach of engineers in the active practice of their profession.

Perhaps this is a consummation for which we should be devoutly thankful. It is un-American, to say the least, to approach the General Government for assistance, except in such cases as may be fairly considered beyond the reach of individual enterprise. It was thought at the time of the agitation for a Government testing machine, that the great expense of its construction was a sufficient reason why it could not be undertaken by private means, and this was true so long as the question was complicated by a desire to secure an instrument which was alike suited for laboratory experiments and the testing of large sections. It was a mistake, however, to attempt the construction of such a machine. The two lines of investigation are separate and distinct, requiring mechanical appliances differing as radically as do the amounts of applied strain; hence it would have been far better, and cheaper in the end, to have built two machines, one of which should be adapted to delicate work upon small specimens, and the other of sufficient power to develop the strength of full sized members without attempting to secure minute accuracy in the measurement of ultimate strains.

In this connection, engineers are more particularly interested in the working properties of structural material in its completed form; and a machine which will develop these properties expeditiously, and at moderate cost, commends itself, without inviting invidious comparison with others having different objects in view.

DISCUSSION ON TESTING MACHINES.

Major F. H. PARKER, United States Army (by letter).—This paper, which has courteously been referred to me, with the "hope" that it "may present matters of sufficient interest to draw from you (me) an expression of opinion" seems to call for the following remarks:

It has been read with interest, and it is satisfactory to know that another machine capable of testing heavy bars is in operation. The demands of the day now require of constructors a full measure of tests of their materials and members of structures before use, and there is, in my opinion, room for more heavy machines.

While the paper as a whole, from its matter and manner, will doubtless receive commendation, that part which refers to the Government machine at the Watertown Arsenal seems to be founded upon some misapprehensions as regards its present status, the work it has done, the work it is doing, and may in the future do.

It is thought that the comments upon and deductions drawn from Major Parker's letter are misleading, and are unwarranted either by the letter itself or the facts as exhibited by the annual reports of work done, and the record of numerous private tests made every year for parties from all parts of the country.

The lament that follows the quotations referred to is entirely gratuitous, and it is desired, in correction of the misapprehension which gave occasion to it, to briefly state the use that the machine has been put to since its completion, and its contributions to engineering knowledge.

It was built by funds appropriated by Congress, and it is required that the tests made each year shall be reported to Congress. This has been complied with, and for several years public and private tests have been constantly carried on and reported.

A synoptical review of the amount and kind of work accomplished by the United States testing machine at Watertown Arsenal, shows that in round numbers 14 000 specimens have thus far been tested, comprising a range of tests, by tension and compression, from the finest wire up to full-sized members of engineering structures, requiring stresses between the limits of 1 pound and 800 000 pounds, the sizes of specimens varying

between limits quite as remarkable as the range of stresses, the shorter specimens having been less than 1 inch in length, and the longest were compression members 31 feet 6 inches.

The limits of the machine are 32 feet 4 inches for compression and 37 feet 3 inches for tension bars; the limiting length for tension bars could, however, with slight modification of the machine, be considerably extended.

The styles and shapes of specimens which the machine is called upon to test are very numerous; its capabilities in this, as well as in many other respects, excite admiration.

The amount of testing has increased year by year. Already about three hundred and twenty thousand pounds weight of material has been tested to destruction, the gross amount of the stresses required to rupture those specimens having a strength exceeding 100 000 pounds, and within 800 000 pounds reaches the sum of over 125 000 tons.

Even this enormous amount of work does not represent what the machine has actually done, the number of repetitions of stresses in the ordinary course of testing would at least quadruple this amount.

It is hardly necessary at this time to more than enumerate some of the lines of investigation which have been carried on with the aid of the United States testing machine. The annual reports of the Watertown Arsenal tests exhibit in complete detail all this information. Suffice it to say that extensive tests have been made upon wrought-iron columns, flat and pin-ended, of various forms in cross-section, and of different lengths. Large cast-iron columns have recently been tested. Brick piers in cross-section, dimensions from 8 by 8 inches to 16 by 16 inches, and in heights up to 12 feet, solid and hollow cores, laid up with face and common hard-burnt bricks, in different kinds of mortars. It is believed that heretofore no tests have been made upon brick piers of any considerable height. These tests were carried out in the same manner that tests with wrought-iron columns were made, that is to say, micrometer observations are recorded of the compresions of the piers under different loads, and of their recovery upon the release of the loads. Similar observations showed the modulus of elasticity of the bricks and of the mortar employed in the construction of the piers. Numerous tests of large-sized wooden posts have been made in single sticks; also two, three and four in combination.

The above are representative compression tests of full-sized members.

Free compression tests have been made to determine the ultimate resistance of wrought-iron, cast-iron and steels of different percentage of carbon; ascertaining the pressures required to cause continuous flow of ductile metals; also tests of metals after having been subjected to cubic compression in a hydraulic press.

Among the tensile tests may be mentioned a very extended series of riveted joints in thickness of plate from $\frac{1}{4}$ to $\frac{7}{8}$ inch.

In these experiments it has been the aim to devolop fundamental principles governing the strength of riveted structures. In the light of these tests, many apparent anomalies of earlier experiments are explained, and a comprehensive knowledge of the subject gained.

Wrought-iron and steel eye-bars have been tested. In connection with the tests of these bars, it was shown that stresses beyond the elastic limit of the metal caused a temporary reduction in the modulus of elasticity, from which the metal recovered after a period of rest.

Preliminary work has been done in a series of tests with hot bars to be carried out with wrought-iron, cast-iron, and steel bars of several grades of metal. A number of the riveted joints were tested at temperatures from atmospheric up to 700 degrees Fahr.

Incidentally, many important facts have been developed in the above tests and other tests relating to the strength of metals employed in the construction of ordnance. The latter tests comprise a very considerable part of the work of the testing machine.

What has been accomplished in the test of material exposed to long-continued service—the tests of hemp, manilla, and wire-cordage, chain-cable, the adhesion of nails and wood-screws in various woods—might be dwelt upon; but enough has doubtless been referred to, to show the general scope and usefulness of the work which has been carried on, the results of which are made public through the reports made each year to Congress.

In addition to the above, there have been made numerous private tests for engineers, iron and steel works, manufacturing concerns, railroad corporations, boiler-makers, bridge works and others; tests to show the quality of the metal, and also upon full-sized tension and compression members.

The parties who have availed themselves of the opportunities, which are extended to all citizens of this country, of having tests made upon this machine, represent varied and important industries, and no inconsiderable benefits are being derived from these tests.

In view of this record of work done, there is no reason to suppose that the Government testing machine is going to cease to be useful, nor to conclude that it is "quite beyond the reach of engineers in the active practice of their profession."

Mr. G. Bouscaren, M. Am. Soc. C. E. (by letter).—Every one interested in bridge-building will be glad to learn that they now have within reach a testing machine of sufficient power to break full-size bridge members of steel. The rapid accession of this metal to the succession of iron in all its industrial applications, has rendered useless for many purposes the elaborate foundation of experimental facts gathered with great efforts by two generations for the support and improvement of engineering practice in the art of building with iron. The close relationship of the two metals is a dangerous snare to those who would presume of their close acquaintance with the one to take liberties with the other. It is quite clear that steel should be one of our best servants, possessing as it does in an exalted degree all the best qualities of iron in addition to some very precious and valuable of its own. But it is also apparent that, owing to a delicate constitution, readily affected by heat and mechanical work, as also by the presence of foreign bodies in homœopathic quantities, it is apt to surprise its friends by very strange behavior, under circumstances where iron would have been entirely trustworthy. Hence the necessity of a thorough understanding in each case of the metal in its finished state before it is used. This knowledge as regards finished structural members can only be had through testing machines of large caliber.

It was thought at one time that the necessary facilities for investigation of this kind would be afforded by the United States testing machine at Watertown. The writer endeavored to have some steel eye-bars tested in this machine last spring, but was informed that the larger bars could not be tested there, the Government officer in charge being adverse to straining the machine anywhere near its limit of capacity, and the smaller bars could not be tested before six months. It is only too true that this machine, upon which so many hopes had been founded, is "quite beyond the reach of engineers in the active practice of their profession."

That its deficiency should have been supplied by the initiation and private enterprise of members of the profession, is a subject of legitimate gratulation for the American Society of Civil Engineers. It can

only be hoped that the good example will be followed by other bridge companies.

No shop can be considered as being fully equipped for the construction of large steel bridges without a testing machine of at least one million pounds capacity.

Mr. GEORGE S. MORISON, M. Am. Soc. C. E.—If no one else is going to say anything, there are two or three points which are practical rather than scientific, which I think it is important to mention in regard to this testing machine.

I have had quite a large number of steel eye-bars broken at the Watertown machine; I have had quite a number broken by the machine which Mr. Macdonald has just described; and I have had iron eye-bars broken by various machines in different parts of the country, and a few steel eye-bars broken by other machines.

When the Watertown machine was first given us (except for the inaccessibility of its location), it was all that I could have asked for. It was undoubtedly a very expensive machine, containing many peculiarities which were unnecessary for the class of work which we usually want done; but it was an excellent machine. The work was done there promptly, and results and reports were given in a way which bore evidence of their accuracy. I had all the test of full-sized bars in the Plattsmouth Bridge made at Watertown. The tests of full-sized bars of the Bismarck Bridge were also made at Watertown. I had the full-sized bars of the Blair Crossing Bridge generally tested at Watertown. But towards the end of the time that tests were made of bars for that bridge, the Watertown machine seemed to become practically useless. The great time expended in getting the tests made, and the facts that the officers in charge seemed to be afraid to use the machine up to anything like its full capacity, rendered the last tests that were made there of little value. The last delivery of eye-bars that were sent to Watertown to be tested were reported on several months after the bridge was open for traffic. Speaking from my own experience, I fully agree with the statement made, that so far as the engineering profession is concerned, the Watertown machine is entirely out of the field. We cannot get reports from it in time to be of any use for the structures that they are made for, and we cannot get bars broken there when the strain required is more than three or four hundred thousand pounds. They will strain them beyond that, but they will not break them.

As regards other testing machines of large capacity, I know of no machine which can be trusted for anything like accuracy excepting this machine at Athens. There are quite a number of hydraulic machines at different works throughout the country which are very useful. They work generally under high pressure, and they will break bars of any ordinary dimensions. I do not think there is a lever machine of high capacity exceeding one hundred or one hundred and fifty tons anywhere in the country which is of the slightest use. There may be. I am not acquainted with the machine at Phœnixville. It is possible that that is sufficiently accurate. This machine at Athens has two or three very decided advantages over any other machine I have seen. It will break any bar, or practically any bar, of a length which can be taken into the machine, with a single stroke. That practically doubles or trebles the capacity of the machine, because a great deal of time is always lost in changing from one hold to another. It applies the strain in a very steady and uniform manner.

The one point which it seems to me we do not know about is, how accurate that machine is in its readings. The evidence would seem to point to its being as accurate as any machine can be. Well, not as any machine can be, but as any machine ever has been which registers simply through hydraulic pressure. For most purposes it is accurate enough. In the specifications which I have been using recently—partly because there was no machine which could be trusted except the Watertown machine, which is inaccessible—I have required no particular elastic limit or ultimate strength on full-sized bars, but have simply required a certain elongation before fracture and a certain character of fracture. So far as I can see, this machine at Athens gives readings, the error of which is very decidedly within any limits which we could get of uniformity of material. It occurred to me though, when I saw the machine, that if it had been built with the cylinder movable and the tail-piece at the other end fixed, it would have been possible to apply at some future day a weighing apparatus either of the Emery style or perhaps of some other, which would have rendered the machine as perfect as anything you need ask for. I will not say that it is not entirely accurate now. The only thing is, we have no means that I can see of measuring the accuracy of its readings. It evidently is much more accurate than any ordinary hydraulic machine.

In the works which I now have on hand, this machine has been a

great deal of use. It has broken very recently a number of eye-bars for the new Omaha Bridge, a number for the John Day 400-foot span which is going out to Oregon, and I expect it will be called on to break some bars for the Rulo Bridge.

The CHAIRMAN (Gen. GEORGE S. GREENE, Past President Am. Soc. C. E.).—What is your opinion of the friction of the piston when that film of water is passing through it all the time?

Mr. MORISON.—That is something we do not know.

The CHAIRMAN.—Do you think there can be much friction there?

Mr. MORISON.—I do not think a great deal, but I do not think we know. I think that is what we want evidence of. I wanted to see tests made of this kind—let a bar be tested in that machine to a certain point which exceeds the elastic limit. Then let that same bar be sent to Watertown and tested and a comparison made between the highest strain put on it in the Athens machine, and the strain at which stretching begins again in the Watertown machine. Tests might also be made at less strains with micrometer measurements.

The CHAIRMAN.—Would not the rest that takes place between the test in one machine and the test in another have some influence?

Mr. MORISON.—The seven or eight months' rest which would take place if it were sent to Watertown might have some effect, but if it were tested at once, I think it would give a very valuable comparison.

Mr. A. H. EMERY.—There are two or three points that I would like to call attention to. First, as regards the use of the machine at the Arsenal and the great delay that has occurred, more especially during the last two years, in getting tests made for outside people. I know personally that for three or four years the department officers have been trying very hard to get Congress to appropriate money for a small machine to relieve the large machine of a great quantity of work of this kind. Every band, every trunnion-piece, every jacket, every barrel of every piece of ordnance that is made over by converting smooth-bore cast-iron guns into rifles by lining, each has to have a piece tested at the Arsenal, and sometimes two pieces from each of those parts. And parties who are doing work for the Government tell me it is not unusual for them to take out a test piece from a band or a barrel and send them to the Arsenal, and sometimes those pieces lie there waiting four months before the returns of the test can be had to determine if the piece is to be finished or condemned.

Mr. MACDONALD.—What sized pieces, Mr. Emery?

Mr. A. H. EMERY.—Very small pieces, that could be tested on a small machine better than on a larger one.

Now the executive officers should not be blamed for that state of affairs, but Congress, that has declined year after year to make this appropriation. I am happy to say, however, that an appropriation is likely to be made within a few months for a small machine.

Now as regards the accuracy of this machine and the one at Athens, I understand the writer of this admirable paper in describing this machine, which certainly seems to be one of great utility, to state that the hydraulic packing friction, that is, the friction of the packings and piston-rod, etc., may be entirely neglected. My own experience differs so far from that, that I should say if we entirely neglected it we will be very greatly in the dark. It is an element of great variability, of great uncertainty, and I am sorry to say of much greater magnitude than is generally supposed. Captain Eads, in constructing his bridge (or Mr. Flad), made a hydraulic machine and a hydraulic gauge for testing it. Experiments on the gauge show that the friction of that gauge-piston was a very considerable percentage; a good deal more than two or three or four or five or six-tenths of one per cent.; a good deal more than two or three or four or five per cent. Mr. Hicks' experiment on pistons of half-inch in the gauge showed those frictions to be very large. In my own experience in that line, I had in the machine at the Arsenal a piston 20 inches in diameter which was packed both ways, and the piston-rod also packed, that is, 10 inches, so that we had three packings; each ran on a very smooth surface. The copper lining was thoroughly rolled and dressed repeatedly, nine different rollings and dressings being taken to increase the bore less than two one-hundredths of an inch. When that cylinder was completed, the surface of the copper was as smooth as glass. The piston-rod itself was finished with emery cloth, so that it was smooth. The packing around the 10-inch piston-rod has to slide on the rod, and the two twenty-inch packings had to slide on the copper. It has a cup-packing, and a brass ring comes in and fastens it down, and the pressure of the water packs the leather against the bore of the cylinder. We usually in tension or compression carry from forty to sixty thousand pounds back pressure; that is to say, if we had 300 000 pounds on the tension side of the piston, we would have 50 000 or 60 000 back pressure on the other side. So if

we had 350 000 pounds on a specimen, we shall have a pressure of 350 000 and a back pressure of 50 000. The surface of these three packings together would represent about one-eighth of the entire section of ram; about the same proportion which we have in this new machine from the long packing and the larger diameter of the cylinder and the long packing on four rods.

Mr. THEODORE COOPER, M. Am. Soc. C. E.—When the piston moves, one packing has to move backwards?

Mr. A. H. EMERY.—Yes. But it is the packing that has the small pressure on it. When this machine was contracted for, the Board believed that the scale which was to be provided would be ample, thoroughly accurate and thoroughly reliable, and that nothing further was needed; but up to that time no scale was made of the variety which is in that machine, larger than ten tons, and it did not seem to them that it was right or proper to make a machine of that magnitude without providing something else, if it could be done. Mr. Charles E. Emery, M. Am. Soc. C. E., provided a system of hydraulic presses for testing machines; provided a plan for a machine for the Board in which the ram was rotated, the motion of rotation being large in proportion to the motion of translation. If, for instance, this motion of rotation is one hundred times the direct motion, then the hydraulic friction or the other friction of sliding the ram, whichever it may be, will be reduced in that proportion. As a matter of fact, those motions, as I put them in there, were much more than 100 to 1. Now, if we would let the ram stand still and not rotate it, the difference between the reading of the scale of the gauges with a load of three or four hundred thousand would be twenty or thirty or forty thousand pounds. Immediately, however, on setting the ram rotating, the scale and gauges correspond. The moment you commenced to rotate the ram, that thirty or forty thousand would disappear.

Now, as to the packing in this Watertown machine we have this case: Mr. Sellers finds that he can put in a recess a little piece of leather and the liquid will flow behind it and throw it out and pack the ram. He says he does not need any gland to force it out; simply put that ring of leather in, and the water will pack that very well. The greater the pressure, the greater the flow of water to hold it up, the pressure between the packing and the cylinder varying with the pressure of the liquid.

I remember very well the first time I went to Phœnixville, the engineer there, Mr. Griffen, showed me their hydraulic forging machine, which was also used for testing. I said, "What do you do with the packing friction?" He said, "That doesn't amount to anything." "How do you know? I say it is very great and very variable." "Well," he says, "we have a 3 000-pound weight which returns it when the load is off." I said to him, "The friction is very large and very variable. It is much more with the new packing than with the old one." We came along later in the tramp through the works to an accumulator. I said, "Is that sufficient for your forging?" He answered, "Well, yes; except sometimes, when we put in a new packing, it is slow." I said, "Oh, there is no difference in the packing." He saw the point, and the blunder he had made in supposing the friction to be small.

The accumulator at Watertown is connected with hydraulic gauges and with the holders. These gauges show the pressure on two 14-inch rams in the holders. Now the rams run up a short distance and seize the specimen. They become stationary. The gauges show the pressure of the liquid forcing them against the specimen; but as they are running up, the accumulator is running down. The friction of motion is very considerably less than the friction of quiescence or rest; and as the two 14-inch rams move up slowly, they seize the specimen and gradually come to rest. The 10-inch ram which was driving them will be slowly settling down. Now, watching the gauges which connect with the holders, we found this state of affairs, that on this 10½-inch ram the load shown on the two 14-inch rams by the gauges would run up, as the accumulator ram was moving down, rapidly, to about three hundred and ten thousand; but as that motion gradually ceased, the holders came to rest by the specimens refusing to yield any further, and the ram, therefore, standing still, this pressure gradually ran down to two hundred and ninety or two hundred and ninety-two thousand. Those differences do not represent the friction; they represent the difference of friction of that 10½-inch ram with a load of about eighty thousand referred in this case to the two 14-inch rams in the holder; but the proportion of loss is the same. You see it is a difference of friction, which represents a very considerable amount. From two hundred and ninety-two to three hundred and ten thousand is a very considerable percentage, which is not the friction, but the difference of

friction between the ram when it was in motion and at rest. So I must consider that the friction on that Athens ram is much more than was attributed to it on high loads, and that it is a very variable one. And, aside from that, my experience in the distortion of all forms of pieces when loaded, is such as to cause me to say that a cylinder supported as this is, receives the load applied on the head, as a beam, with a depth of the web equal the length of the cylinder and a thickness equal that of the walls of the cylinder. Those parts of the cylinder constituting the web of the beam are in the curved lines which constitute the walls of the cylinder. The yielding of those is such as to bring a considerable pressure on the piston. That pressure is unknown and variable, depending on the load, and depending on the position the piston may have at different times in the cylinder. As the piston moves toward the middle, it will be different from what it would be at the end. So that those two sources of packing friction and the friction of the piston itself in the cylinder, are very considerable and of variable and unknown amounts.

Now when we come to the pressure itself, it is measured by two gauges whose exact properties I know not. But my experience with all the gauges that I have tested would tend to cause me to say: You must not rely upon that as being absolutely correct. I went to Mr. Willing to make me a gauge, and he said if I would let it down to 600 pounds to the square inch he would make a very accurate one. I said, "Make me one." He made what is known as a Bourdon gauge. That gauge showed its full reading, 600 pounds, with a load of 525 pounds to the square inch. Now you are not to infer that these gauges they are using are of any such degree of error as that, but we may infer that there is a possibility of considerable error. Now another point with all of these gauges which I have tried, both the Willing and the others, is that they do not run up and down at the same points with the same load. That is to say if I bring a regularly increasing pressure which should bring me a certain curve, when I come down to the same pressures I will not get the same ordinates. In the case of the Willing gauge mentioned, which was the bent-tube gauge, it represents a very large class of our gauges, and that varied from nothing to 25 pounds in the nominal readings going up to 600. That should be reduced in the proportion the other way—from 600 to 525; but it never would run up twice precisely alike with the same pressure, and never run down in the same curve at which

it ran up. I have no doubt they (the Athens people) have a much better gauge than that—I should hope so; I should presume they have—but how much better it is I cannot say. I should doubt very much if that gauge was true within one per cent.; I should be very much surprised if it were found so. I would mention here as to how I tested these gauges to know their exact pressures. We have what I call a plate fulcrum machine—a lever machine which is absolutely frictionless—on the platform of which we carry 60 000 pounds, or any smaller load we choose. It will show on that platform a load of a tenth of a pound distinctly. On that platform we set a hydraulic support with a carefully made area of 80 square inches, 50 square inches, $33\frac{1}{3}$ square inches, 10 square inches or 6 square inches, as the case may be. We connect liquid with that and the gauge. There is a little free span, the size depending on the magnitude of the pressures, however great, varying all the way from as high as three-tenths of an inch down to five one-hundredths of an inch. We connect the liquid with this support with the gauge to be tested. This represents a large column. This is magnified. If this column moves up and down a little during the work, there will be but little force put into this diaphragm to bend it. I have applied a gauge to find how much the column yields with a load. They yield from half a thousand up to two-thousandths of an inch with a full load. Loading this pressure support in this weighing scale, we apply a pump and force in a quantity of liquid just sufficient to keep this column at a constant height, and the gauge by which we regulate that will show very distinctly a ten thousandth of an inch; so there is no difficulty in keeping that column within a ten thousandth of a level all the time. Thus we have the means of absolutely knowing that our pressures here are substantially what we represent them to be, and they are not what the gauges represent them to be. But, as I have said before, they differ very materially,

In regard to testing some large bars up to and past the limit of elasticity in the Athens machine, and subsequently sending them to the Arsenal to see what load will increase their stretch, I would say, all my experience goes to show that a certain load having been applied to such a bar, sufficient to pass the limit of elasticity and subsequently removed, the second load, which will start that again and give no increased stretch, will be found to be very considerably larger than the first. If then we will compare those loads, we must take that bar at a certain temperature,

and load, not sufficiently to reach the limit of elasticity, but keep below it; or if we do pass it, let the bar cool down and begin again, and pass carefully in certain times and with certain carefully weighted loads, and note carefully the corresponding lengths of the bar. Then put it in the other machine and see if those lengths remain the same. We shall find the bar in that case will act as a very excellent dynamometer—if we do not pass the limit of elasticity—provided we keep it at the same temperature, and the measuring apparatus at the same temperature.

There is one more point I would like to mention. The desirability of a large and small machine is fully recognized, and I have designed a small machine. The stroke of the piston in this machine is 25 inches, or sufficient to move the entire length of the specimens which can be tested therein, and they are measured in just about this position before the observer [indicating a height about fifty inches from the floor]. The tie-rods or side members are 21 inches apart in a vertical plane, so there is every facility to see exactly and observe what is going on. The compression tests are in another part of the machine, which is not disturbed while you are testing for tension, nor are the tension-holders disturbed while you are testing for compression. You pass from one to the other without disturbance or change of the machine in any way.

In regard to large machines, I would say that during the past year I have designed one which was called for by one of the departments. They have not succeeded yet in getting their appropriation. It was a machine for testing all sorts of bars—rounds, flats, squares, etc.—up to 25 feet in length, with loads up to 400 000 pounds, and chains 90 feet between pin centers with 6 feet stretch. The piston of that machine has a motion of 8½ feet. I have also designed during the past year another machine for loads of 1 200 000 pounds for both tension and compression, which will take in lengths of 50 feet between pin centers and stretch them, if the metal is equal to it, 12½ feet. The columns which would go in that case would also be 62½ feet length at pin centers. The holders for that machine will take round bars up to nearly 6 inches, all sizes down to a little fine wire; square bars, all sizes, from the smallest made up to the maximum size of iron or steel, which 1 200 000 pounds will break; also all sizes of plates or flat bars up to widths of 16 inches, and eye-beams, 15 inches of wrought-iron, and pull them in two. As regards recoil, the machine stands up and takes it. There are no appliances, as there are in the Athens machine for taking them up by friction, but the

machine is able to take all the shock of recoil without injury. The recoils in the case of steel links of the maximum length which can be tested, and which break through the eye of the bar at either end with the maximum load of the machine, are very large; would give us a recoil in that case of about seventy thousand foot pounds. We do not expect any injury whatever from a recoil of 70 000 foot pounds. The stroke of the ram is 13 feet. This machine is not built, except on paper. The press moves from one end of the machine to the other in two or three minutes by the mere starting of a little belt. I should say two minutes is sufficient to carry it from one end of the machine to the other, and it is stationed at any desirable point very quickly and without any back-lash whatever. The holders for tension have, as I stated, unusual capacity; they do not have to be removed in passing from tension to compression. The scale is changed from tension to compression by a little turn of a crank. The compression holders, however, must be put on the front of the tension holders, and then removed when you want to pass to the tension business; but the tension holders are not removed for any operations in the use of the machine.

Mr. Theodore Cooper, M. Am. Soc. C. E.—There has been much error upon the subject of hydraulic packing. The careful experiments made at St. Louis upon hydraulic packing, I believe have never been published. As it is desirable to have them more widely known, an abstract of them, with the apparatus for determining them, will be submitted as an appendix to this paper.

Past President Henry Flad devised a very simple apparatus for making these tests and supervised the experiments. From a careful study of these and other experiments I have no belief in the claim made as to the great friction (relative) of hydraulic packing in such sized rams as are usual for hydraulic testing machines. On little plungers of the size of one's fingers, you can get friction enough to resist motion under any practical pressure, but as we pass to plungers of larger diameter the friction rapidly diminishes, and for plungers of 18, 20 or 24 inches diameter I doubt if the friction of a properly made packing under pressures of 600 and more pounds per square inch, amounts to one-half of one per cent. of the total pressure exerted.

Certainly for practical purposes we can call a testing machine accurate if the results can be obtained within this limit. Here is the merit of the claim made by Mr. Macdonald for the machine under discussion.

He does not pretend to weigh the strains to such a degree of accuracy as would be required in the extreme refinements of laboratory investigations. For testing the strength of practical work we do not desire to find the strains within such refinements as a fraction of 1 per cent. Life is too short to attempt, in practical work, this extreme accuracy that my friend Mr. Emery would desire. I admire him for his desire for extreme accuracy, but it is misplaced when applied to every-day practice.

When searching for the laws governing the strength of materials and analyzing the various influences effecting the same, accuracy is imperative. For such purposes the Watertown machine may be admirably fitted.

But for the constant demands of practical construction, the machine here described by Mr. Macdonald is more accurate than a more delicate and refined machine. It gives us directly, by one application of the pressure, the ordinary elements of the test-piece. Where it is necessary to take several hours to make a test and elongate the piece by successive steps we get a different result, and in my opinion one of less accuracy for comparative purposes than when pulled directly at one operation.

Mr. EMERY.—May I interrupt you a moment?

Mr. COOPER.—Certainly.

Mr. EMERY.—I think there is no length tested on that machine but that one setting of the ram is sufficient to carry it through.

Mr. COOPER.—I may be mistaken then, but I have been informed that much time is wasted in changing for a new attachment.

Mr. Emery has made one point that may be important in reference to the distortion of the cylinders by the attachment of the side rods. This, however, is merely a matter of the proportions of the cylinder.

Mr. CHARLES E. EMERY, M. Am. Soc. C. E.—This machine undoubtedly has questionable features, but on the whole I like it.

Briefly reviewing the whole subject: Mr. A. H. Emery has mentioned my connection with the bids for the Government testing machine at Watertown, but the enormous friction of hydraulic packings can be still more forcibly illustrated by the experience there than he has stated.

I submitted a plan of a hydraulic machine in which the ram was to be revolved by power as it was forced out by the pressure to produce the strain. By making the rotary movement very much greater than the movement of translation, the surface of the ram would evidently have the same motion as if it were a fine screw, and the friction due to

such movement would be distributed between the direct and transverse movements, precisely in proportion to the relative distances moved. For instance, if the rotary movement were ninety-nine times that of translation, ninety-nine per cent. of the friction would be overcome by the external power revolving the ram, and the difference between the pressure in the cylinder and that on the specimen could not be greater in any case than one per cent. The principle is well illustrated by workmen moving a heavy loose wheel on a shaft. If two or three men revolve the wheel, a workman at the side can push it along the shaft with his heel, the two forces causing a spiral motion, even though the sliding force be very much too small to produce movement unless combined with the other. The principle was illustrated before the Board by placing a heavy weight on a slide, when it was found that the most delicate diverting force would move the weight laterally, so long as the slide was pulled through beneath it. Some members of the Board expressed a wish that this principle could be embodied in the straining press end of the A. H. Emery machine, so that if any of the delicate work he proposed to provide for the weighing end should require experiment, or cause delay, the Board would still have something which would give closely approximate results in a reasonable time, and one apparatus would act as a check on the other.

Mr. A. H. Emery finally arranged with me to apply my device to his machine, though it could not be done as simply as in the plan I submitted, on account of his double-acting piston and other differences in construction. To accomplish this, he designed a separate piece or apparatus—practically a short duplicate of his straining cylinder—to take the thrust of the piston in the latter, and upon the carriage supporting the same he erected the machinery for revolving the ram and pistons.

Mr. A. H. Emery will please excuse me if, at this point, for the purpose of showing the great friction of hydraulic packings, I call attention to differences of opinion which arose between us originally on the subject. My experience with the variable friction of steam-engine valves and packings led me to suppose it might be possible, at times, that the friction of the packings would be as high as ten per cent. of the total load on the hydraulic plunger. At any rate, to be safe, I designed the rotating apparatus for this strain. A large heavy worm-wheel, with coarse pitch, was to be secured to the ram and operated by two worms, engaging with opposite sides of the wheel. Mr. A. H. Emery insisted

that the provisions made were unnecessarily strong, and in making his designs he applied a smaller sized spur-gear with teeth of less pitch, and operated the same with a pinion on one side only.

Mr. A. H. EMERY.—On both.

Mr. C. E. EMERY.—I had forgotten that; at any rate it was found on trial that the apparatus provided would not revolve the ram up to the full capacity of the machine.

Mr. A. H. EMERY.—Not half.

Mr. C. E. EMERY.—Not half the capacity of the machine. It seems that my caution or obstinacy was nearer right than his calculations in that matter.

Mr. A. H. EMERY.—I must plead ignorance. The friction is fully twice what I expected.

Mr. C. E. EMERY.—Everything was fitted micrometrically in all that work, and whether or not this had something to do with the result I do not know. The whole A. H. Emery machine, from one end to the other, is marvelous in its ingenuity, marvelous in its execution, and marvelous in its performance. It is a monument of which any one may well feel proud, and a credit to American engineers and mechanics. I may add that his machine, as originally designed, operated so well that there has never been any occasion to perfect the attachment made to apply my principle. The experience had with that part of the apparatus strengthens the point that the friction of ordinary hydraulic packing is very large. I, however, as a steam engineer know something about the kind of packing used in the testing machine now under consideration; and it is curious that it never occurred to me before that this was the kind of packing to be used under such circumstances. The friction of such packing, under certain practical conditions, really *reduces* as the pressure increases, and I know it.

Very frequently, in taking what is called a "friction diagram" from steam engines, for the purpose of ascertaining the power required to operate the engine when unloaded, we get a result which is called the friction of the engine, but is really no such thing. I have tested the same engines when loaded, with indicators on the cylinders and dynamometers on the shafting, and found that the friction of the whole load, which included the friction of the packings, was less than was shown in taking what were called friction diagrams.

Mr. A. H. EMERY.—Under the same speeds?

Mr. C. E. EMERY.—Yes, under the same speeds. I will explain, for the information of those not familiar with the technical details, that the friction of the load, as we understand it in testing engines, is the additional work thrown on the bearings when the engine is loaded and doing external work. At such times the pressure on the piston is greater, and this causes increased pressure on all the working parts and in all the bearings, which increased pressures produce the additional friction termed the friction of the load. Now I say that I have observed actually, in some cases, that the friction of the whole load, tested carefully in the way stated, was less than was shown as the friction of the unloaded engine when the latter was determined by the use of the indicator. I explained this on the theory that the stuffing-boxes were necessarily screwed up to resist the pressure of the steam at the maximum load, and that, when there was no load on, the pressure in the cylinders being diminished, the elasticity of the packing caused it to grip the rods like a vise. I therefore, afterwards, in writing out instructions for engine tests, directed that the packing on all the rods be loosened before taking friction diagrams. In the testing machine under consideration, the packing is of the same kind as is customarily employed on the rods of steam engines, and is compressed by a gland in the same way. The pressure on the gland must be sufficient to force the packing against the side of the cylinder, and upon the piston rods with sufficient force to resist the pressure of the water. It seems to me reasonable, therefore, that when the water pressure is reduced, the elasticity of the packing causes a greater pressure against the surface of the cylinder, and a greater friction than when the pressure is at its maximum. The paper states that a tank is provided 4½ feet below the cylinder, and that the partial vacuum produced by the 4½ feet head of water is sufficient to retract the piston. This is done when there is no pressure in the cylinder, and when, on the principle above explained, the friction is at a maximum. It follows, therefore, that the friction can at no time be greater than is represented by the load due to a head of 4½ feet of water on the area of the piston, and from the consideration of the principles above stated, that the friction must be actually less than this when tests are being made and fluid is admitted under pressure to produce the strain.

If the facts and principles here stated apply to this particular case, and I see no reason why they do not, the machine is certainly not only

very useful for rough work, but will show practically accurate results for moderate strains. The point raised by Mr. A. H. Emery, that the method of connecting the frame to the cylinder may cause distortion of the latter, and produce friction which cannot be calculated, is an important one which should not be overlooked. That matter needs investigation.

Mr. COOPER.—May I interrupt you to ask a question of Mr. Macdonald? Do you notice in the working of the machine whether the volume of water passing the piston is changed?

Mr. MACDONALD.—I was going to say that one object of leaving the cylinder open was that a thorough inspection might be made during the test, and the observation of that thin volume of water would convince either of these gentlemen that there was no distortion there which was appreciable.

Mr. C. E. EMERY.—That was a matter, I said, which needed investigation. If such investigation has been given, the question is already answered. I am very much gratified to see this application of a very well-known device. I will only add that, even granting the applicability of the principles I have stated, the accuracy of the machine will depend upon the way in which it is maintained. If finally it needs a head of water of eight or ten or more feet to retract the piston, it will show that the packing is out of order. If the machine is to be used regularly by a man who has pride in the work, and the conditions stated in the paper be maintained, to wit, the packings kept so free that the piston will be retracted by a head of water of four and a half feet, that, of itself, it appears to me, will insure the substantial accuracy of the machine, and for that reason I say I like it.

In general, as has been stated, there will be required machines of different classes, one for the very fine work for which the A. H. Emery machine is so well adapted, and which it does so well, and others of the rough-and-ready type, which will do practical work in a practical way in a reasonable time, and which will give practically correct results. The machine under consideration, it appears to me, will answer the latter requisite, and from such examination as I have been able to give the subject, I think it will do it well.

Mr. COOPER.—During the construction of the St. Louis Bridge, the steel members and samples of the steel were tested at the steel works upon a large hydraulic testing machine of a crude construction. I per-

sonally used this machine for months, testing thousands of samples. Occasionally duplicate samples were forwarded to Pittsburgh to be tested upon the St. Louis lever machine, a very accurate machine. A comparison of these duplicate tests made upon this machine by another observer with those made by me on the hydraulic machine at the steel works, satisfied me that there was no great error in this machine. An allowance of one per cent. for friction was made upon the strains obtained.

I do not believe that in a practical machine of this character the friction will be enough to give any reasonable doubt of the results. Of course, with new packing or badly-made packing the friction is considerably higher than with good and well fitted packing.

In regard to the gauge mentioned as used with the machine under discussion, the Shaw mercurial gauge I believe to be a very good one when kept in good order, and occasionally verified by testing. Like all apparatus it needs care and regulation. I have used this gauge in connection with one devised by Past President Henry Flad to check its correctness. The latter gauge was made of a selected steel ribbon about ten feet long, carefully tested for its comparative elasticity under the range of pressures desired, and the pressures recorded by suitable multiplying gear. It is an inexpensive apparatus.

Mr. C. E. Emery.—I did not quite cover all the points I intended in my remarks. Referring to the two kinds of machines desirable—one, the accurate machine which we have already in the A. H. Emery machine, and the other, the rough-and-ready one, to be sufficiently accurate not to mislead us—I have hoped and urged that the parties now controlling the A. H. Emery machine, as well as my own ideas on the subject, would bring out a machine with a rotating ram as I proposed, and put it on the market, as it would furnish a comparatively cheap apparatus sufficiently accurate for general purposes. Referring to the machine under consideration, there will necessarily be the same feeling in the minds of engineers that Mr. Morison has shown here, that there is a chance of error and a doubt as to how much it is. It is therefore desirable to have machines the accuracy of which can be tested. I trust that the provisions for retracting already used in the machine under consideration do furnish such a test on the principles I have already enunciated; but to prove that this is true, I would suggest to Mr. Macdonald that he have a light steel eye-bar tested in the A. H. Emery machine,

well within the limit of elasticity, and carefully note the elongations under different strains with a microscopic device or a compound lever apparatus of the kind used by Colonel W. H. Paine, M. Am. Soc. C. E., and then keep the same as a test bar to be strained within the same limits by the machine under consideration in order to compare the gauges, and prove accurately what the friction is. The same can then be shown engineers when and as often as they may desire. Meanwhile I wish that Mr. A. H. Emery had a contract for fifty of his very nice machines. I also wish he would turn his mechanical talents to building some of the rotating-ram machines according to my idea, to be used for the very purpose for which the machine under consideration has been designed.

Mr. A. H. EMERY.—I would like to say in that connection, that the design of the six hundred-ton machine I have made is a cheaper machine to build than the other would be, designed equally good.

Mr. A. M. WELLINGTON, M. Am. Soc. C. E.—I would like to ask Mr. Charles E. Emery one question in connection with this ram that he speaks of. If it revolves one hundred times the speed it moves lengthwise, does it not almost completely eliminate the friction?

Mr. CHARLES E. EMERY.—It would. The friction would be as the velocities. If the transverse movement of the surface of the arm were 99 times the movement of the translation, the pressure would represent the strain on the specimens within 1 per cent.

APPENDIX.

By THEODORE COOPER, M. Am. Soc. C. E.

Tests of Friction of Hydraulic Cupped-Leather Packing.

Made at St. Louis.

The accompanying tests were made at St. Louis in the early stages of the construction of the St. Louis Bridge, to determine the friction of the packing in the hydraulic testing machine to be used for testing the materials of construction. The apparatus was devised by and the tests made under the supervision of Henry Flad, Past President Am. Soc. C. E.

Plate IV shows the details of the apparatus for making the tests. The casting representing the cylinder contains two leather packings. These were varied in size, as shown in full upon the drawing, from $1\frac{3}{8}$ inches to $\frac{1}{8}$ inch in width. The friction was measured by actual weights imposed. The pressure (hydraulic) was obtained by a hand pump, and was measured by means of a mercurial column 46 feet high. Two sizes of cylinders were used, one 9 and the other 6 inches in diameter.

Column one of the table gives the pressure in feet of mercury; column two the pressure per square inch in the cylinders (this has been corrected for the errors in gauge due to the falling of the surface of the mercury in the reservoir); column three gives the total pressure upon the area of a cylinder 9 inches in diameter; column twenty-three gives the total pressure upon the area of a cylinder 6 inches in diameter. The columns headed W give the actual weights necessary to move the cylinders against the friction of *the two packings* under the several pressures.

As two or more tests were made on each packing, it will be noticed how the friction reduced for the last tests in comparison to the first test, showing thus the difference between a new packing and the same after a moderate use. The difference due to the size of the packing is also shown by the several columns headed $1\frac{3}{8}$, $1\frac{1}{8}$, etc., and which give the width of the bearing side of the packing.

Columns twenty, twenty-one and twenty-two, headed percentages for one packing, give the relation between the friction reduced to one packing (the apparatus contains two packings) and the total pressure upon a ram of the size experimented upon. The first of these columns gives the maximum friction in percentage; the second, the average of all the tests; and the third, the maximum friction. So that the range can be seen at a glance.

It will be noticed that the relative friction reduces with the increase of the pressure per square inch for both sized rams. Also that the relative friction of the rams is less as the diameter of the rams is increased.

The assertion made by the writer in the discussion upon Mr. Macdonald's paper, that for such rams and pressures as were usually employed in testing machines the friction would not be one per cent. of the full load, and probably less than one-half of one per cent., is supported by these tests. These conclusions are confirmed by a comparison with Hicks' experiments. (See page 32.)

In addition to the tests on the friction of hydraulic packing with the longitudinal motion of the plungers, tests were made at St. Louis upon the friction of rotating the plungers. They were made by inserting a lever in the eye-bolts shown on the drawing of the apparatus, and weighing at a fixed leverage the amount of the resistance to rotation. The following table gives an abstract of these, reduced to the circumference of the plunger:

AVERAGE FOR ONE PACKING.

Size of the Packing.	9-INCH RAM.		6-INCH RAM.	
	Pressure = 0.	Pressure = 273 pounds.	Pressure = 0.	Pressure = 273 pounds.
Inches	Pounds.	Pounds.	Pounds.	Pounds.
1 3/8	23	300	8	140
1 1/4	61	250	12	164
1 1/8	50	250	8	114
1	6	200	8	118
7/8	6	184	6	104
3/4	6	147	....	....

ABSTRACT OF HICKS' EXPERIMENTS.

Friction of a Plunger one-half inch diameter, Leather Washer Packing.

Pressure per square inch.	Friction in Percentage of Total Pressure on Plunger.		
	New and stiff leather.	Leather used before.	Second leather.
Pounds.	Per cent.	Per cent.	Per cent.
10	26	18	18
20	12.5	8.5	13
30	12	7.6	10
40	10	6.5	10
50	9.6	5.4	9.6
60	9	4.9	9.0
80	5.6	4.1	7.7
100	5	3.8	7.4
120	4.3	3.3	6.3
160	4.7	3.0	5.6
200	3.3	3.3	4.8
240	4.1	3.4	4.1

Friction of a Plunger four inches in diameter.

	Leather, new and stiff, and sparingly lubricated.	Leather, well worn, and well lubricated.
Pounds.	Per cent.	Per cent.
188	4.6	2.13
446	2	1.25
673 to 5 865	1.55 to 1.07	0.95 to 0.63

Friction of a Plunger eight inches in diameter.

443 to 1 882	0.46	0.42
6 375	0.50	0.33

Size of ram.....	9-inch ram.																	
Size of packing.....	1⅜ inches.			1½ inches.			⅞ inch.		⅝ inch.		⅜ inch.							
	Weight W to move ram.																	
Gauge, feet.	Pressure,* lbs. per square inch.	Total pressure on area of ram	W =			W =			W =		W =		W =					
0	0	0	24	24	...	100	85	86	120	102	26	24	28	28				
2	11.87	775	54	50	...	122	102	103	130	116	40	32	58	36				
4	23.74	1 510	84	70	62	131	109	113	140	128	53	59	66	66				
6	35.61	2 265	110	25	70	144	123	126	152	138	63	75	87	80				
8	47.48	3 020	113	110	88	164	134	134	164	148	86	92	97	92				
10	59.35	3 775	123	120	103	180	147	142	176	158	94	104	110	102				
12	71.22	4 530	133	130	119	183	158	148	188	175	104	110	122	112				
14	83.09	5 285	154	140	131	193	168	156	200	185	116	122	137	122				
16	94.96	6 040	170	152	139	203	180	166	208	194	127	132	143	134				
18	106.83	6 795	174	168	150	213	189	178	220	203	139	144	153	144				
20	118.70	7 550	184	178	164	224	198	186	230	211	159	154	167	153				
22	130.57	8 305	197	188	178	234	208	194	240	220	170	166	176	162				
24	142.44	9 060	201	200	192	244	218	202	250	230	176	176	186	172				
26	154.31	9 815	212	215	206	255	228	214	258	241	186	186	196	180				
28	166.18	10 570	220	225	220	263	238	226	268	249	196	192	206	191				
30	178.05	11 325	230	239	234	273	248	236	278	257	210	205	217	201				
32	189.92	12 080	242	253	246	283	260	250	286	268	220	215	227	210				
34	201.79	12 835	252	267	260	293	272	254	294	280	228	225	238	218				
36	213.66	13 590	264	283	260	303	282	264	302	290	238	237	248	228				
38	225.53	14 345	280	299	274	308	292	271	312	300	246	244	257	238				
40	237.40	15 100	308	305	292	315	304	279	322	310	256	254	266	248				
42	249.27	15 855	336	326	306	327	314	289	332	318	266	264	276	258				
44	261.14	16 610	336	326	317	333	320	299	340	326	276	276	286	264				
46	273.00	17 368	336	326	329	338	328	309	348	334	286	284	286	272				
0	.....	.....	...	...	...	...	...	...	...	...	...	...	...	...				

* Correcte

Indicates

TESTS ON FRICTION OF HYDRAULIC CUPPED LEATHER PACKING.

MADE AT ST. LOUIS.

	⅜ INCH.			½ INCH.			PERCENTAGE FOR ONE PACKING.				1⅝ INCHES.				1
AM.	W =			W =			Max.	Aver.	Min.	Total pressure on area of ram.	W =				
24	28	28	24	24	20	24	....	....	....	....	25	10	10	10	22
32	58	36	46	50	44	39	8.	4½	2.	335	51	20	23	21	40
59	66	66	66	68	58	58	4.3	2.7	1.8	671	66	30	32	27	53
75	87	80	76	82	76	76	3.35	2.0	1.4	1 007	71	39	38	36	70
92	97	92	86	109	88	88	2.7	1.85	1.4	1 352	81	43	44	41	90
04	110	102	98	124	100	107	2.4	1.64	1.24	1 687	91	49	51	47	93
10	122	112	108	136	116	122	2.0	1.50	1.15	2 014	105	56	58	52	101
22	137	122	120	146	130	132	1.9	1.40	1.1	2 350	65	62	66	58	110
32	143	134	131	158	142	147	1.7	1.30	1.05	2 685	71	71	65	63	119
44	153	144	143	168	162	160	1.6	1.24	1.02	3 022	81	77	70	67	133
54	167	153	153	180	174	172	1.52	1.20	1.00	3 358	91	81	76	74	144
66	176	162	161	194	186	190	1.44	1.15	0.97	3 693	91	85	83	78	144
76	186	172	171	203	196	200	1.38	1.11	0.94	4 029	97	93	85	85	148
86	196	180	179	213	208	212	1.30	1.08	0.91	4 364	108	98	91	89	148
92	206	191	187	223	218	222	1.27	1.05	0.90	4 700	116	100	99	95	148
05	217	201	198	233	228	230	1.22	1.02	0.87	5 035	122	109	107	102	153
15	227	210	208	343	242	244	1.18	1.00	0.86	5 371	130	117	107	106	158
25	238	218	216	254	258	260	1.14	1.00	0.84	5 706	134	124	115	108	172
37	248	228	226	264	268	268	1.15	0.97	0.83	6 042	141	132	123	115	174
44	257	238	236	278	278	268	1.08	0.96	0.82	6 377	149	137	129	120	176
54	266	248	246	288	288	268	1.07	0.94	0.81	6 713	149	141	132	123	180
64	276	258	256	307	299	278	1.06	0.94	0.80	7 048	156	150	137	131	188
76	286	264	256	315	311	285	1.02	0.91	0.79	7 384	163	156	141	137	198
84	286	272	266	315	323	289	1.00	0.90	0.70	7 719	170	166	146	142	198
...	...	...	...	...	...	...	....	....	....	....	...	10	10	...	...

* Corrected for error of mercurial gauge due to the depression of the mercury in the reservoir.

† Indicates that the pressure was let back and readings taken on the falling pressure in the second column.

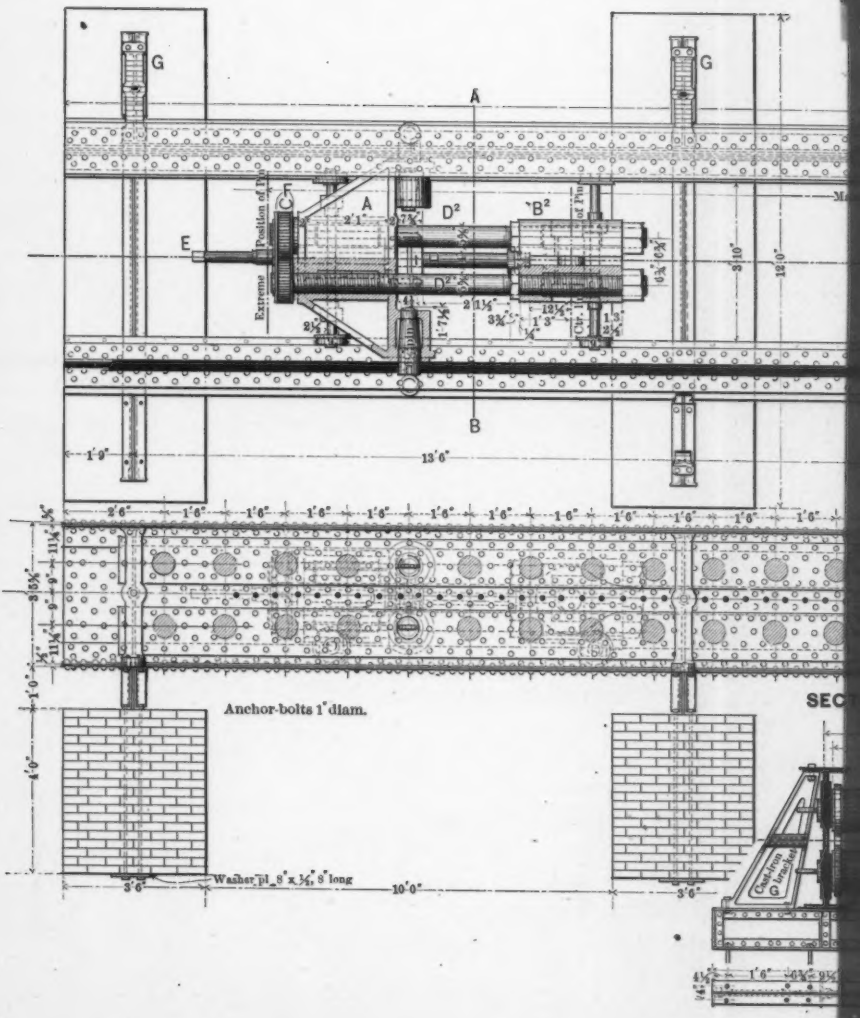
KING.

6-INCH RAM.

	1¼ INCHES.				⅞ INCH.				½ INCH.				⅜ INCH.						
	WEIGHT W TO MOVE RAM.																PERCENTAGE FOR ONE PACKING.		
	W =				W =				W =				W =				Max.	Aver.	Min.
10	22	20	20	20	22	15	15	15	17	15	15	...	10	9	9	9	....	....	....
21	40	35	46	44	42	30	21	23	29	28	29	...	25	19	22	19	7.6	4.45	2.83
27	53	55	64	62	58	40	27	29	39	34	37	...	36	23	28	22	4.92	2.99	1.64
36	70	75	80	77	70	47	33	33	47	38	45	...	46	33	38	32	3.97	2.48	1.59
41	90	83	88	85	76	57	40	39	58	43	51	...	57	43	44	40	3.33	2.15	1.44
47	93	91	88	98	81	67	47	47	64	49	57	...	64	49	51	46	2.91	1.92	1.36
52	101	92	104	103	95	67	52	53	70	57	63	...	73	57	57	54	2.61	1.79	1.29
58	110	96	116	107	100	75	46	53	70	63	70	...	78	63	63	60	2.47	1.59	0.98
63	119	102	124	112	100	80	51	59	75	71	79	...	82	69	69	68	2.31	1.50	0.96
67	133	107	124	116	104	90	65	68	81	79	86	...	82	74	73	74	2.20	1.44	1.07
74	144	117	124	116	115	94	71	74	87	85	89	83	86	78	80	82	2.14	1.37	1.06
78	144	122	126	121	117	94	78	78	97	91	93	87	92	82	86	88	1.95	1.31	1.06
85	148	127	131	132	121	100	82	92	101	97	99	95	97	86	91	94	1.83	1.27	1.02
89	148	135	137	142	121	110	88	98	111	113	107	101	101	90	87	101	1.69	1.24	1.00
95	148	135	150	149	129	110	94	98	117	119	112	105	101	95	101	106	1.59	1.21	1.00
02	153	153	150	149	134	131	98	104	120	125	117	110	105	100	107	114	1.52	1.19	0.97
06	158	153	153	149	139	134	102	108	129	129	124	119	105	105	113	116	1.47	1.16	0.95
08	172	155	159	151	148	135	108	112	137	133	128	124	110	110	121	121	1.51	1.14	0.94
15	174	163	163	167	152	143	117	117	143	137	132	128	115	115	125	125	1.44	1.13	0.95
20	176	166	168	167	155	147	125	123	153	141	136	134	119	119	132	131	1.38	1.11	0.93
23	180	180	175	177	159	157	127	127	157	145	140	140	123	123	137	137	1.34	1.09	0.92
31	188	180	185	175	164	161	133	133	161	151	146	146	128	128	141	145	1.33	1.08	0.91
37	198	184	188	182	169	165	137	137	165	155	152	152	133	133	151	151	1.34	1.07	0.90
42	198	188	193	193	175	169	141	141	167	167	158	158	138	138	164	164	1.28	1.06	0.89
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	....

d column.

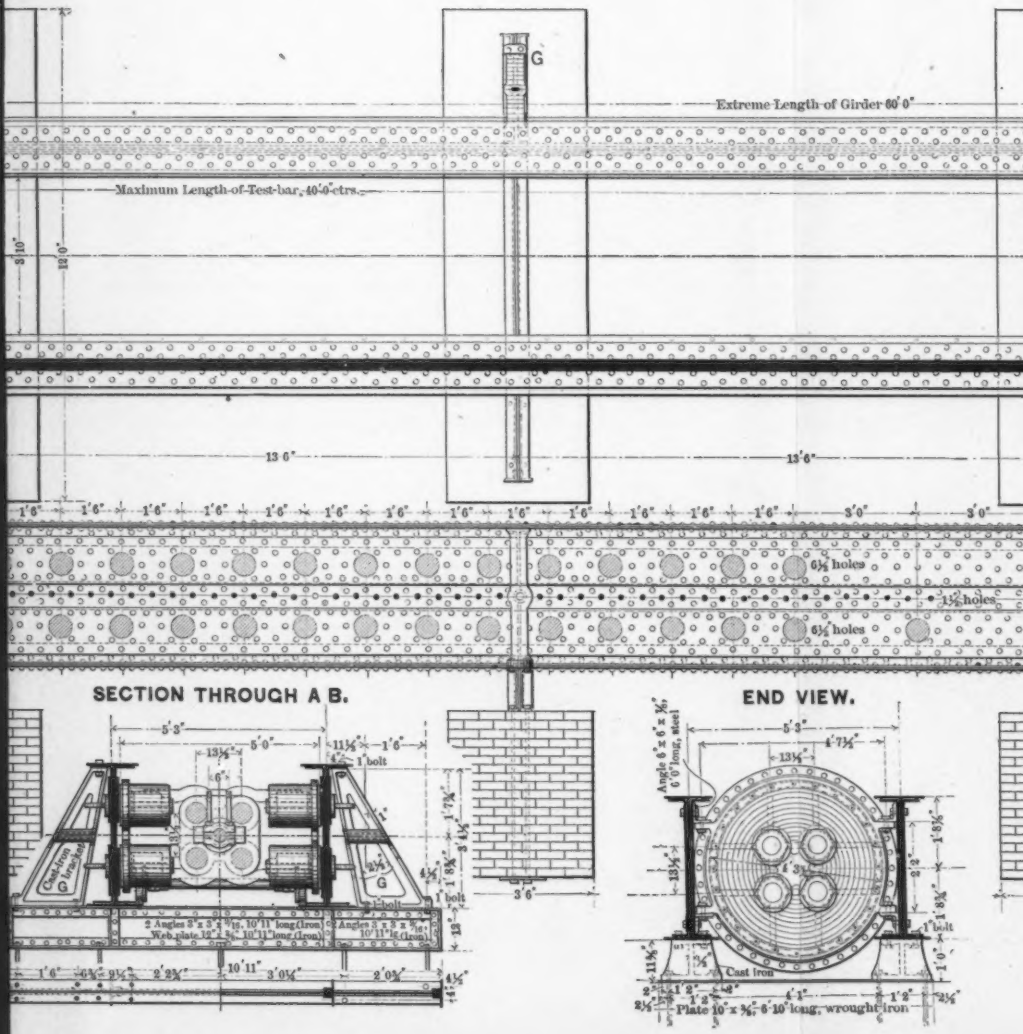
GENER



G
G
A
A
B
B²
D²
D²
C
F
E
Extreme Position of Pin
Ctr. Line of Pin
2'1"
2'7¾"
2'1½"
3¾"
1'3"
¼"
12½"
1'3"
2½"
6¾"
6¾"
3'10"
12'0"
1'9"
13'6"
2'6"
1'6"
1'6"
1'6"
1'6"
1'6"
1'6"
1'6"
1'6"
1'6"
1'6"
1'6"
1'6"
3'5¾"
11¼"
9"
11¼"
1'0"
4'0"
Anchor-bolts 1" diam.
Washer pl. 8" x ½", 8" long
3'6"
10'0"
3'6"
SEC
Cast-iron bracket
1'6"

ENERAL PLAN OF 1,200,000 LBS. TESTING MA

MAXIMUM WATER-PRESSURE 600 LBS. PER SQUARE INCH.

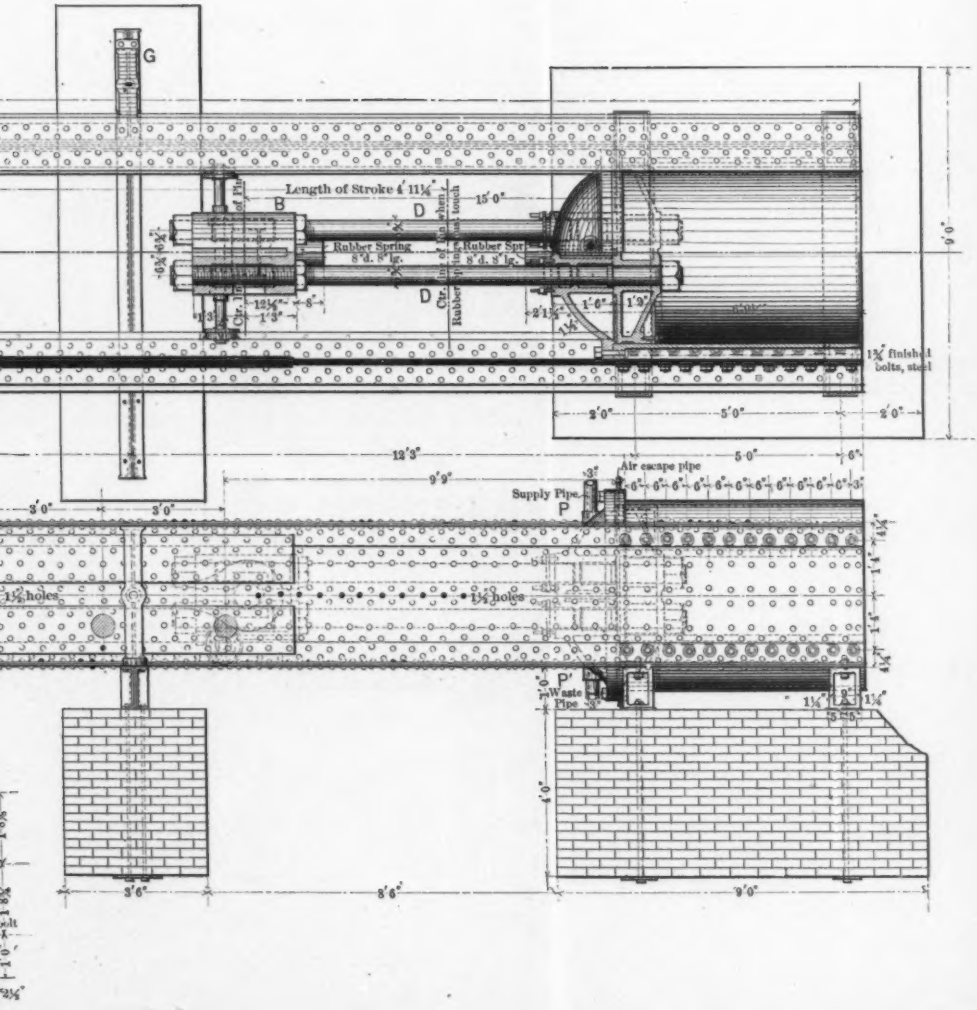


SECTION THROUGH A B.

END VIEW.

MACHINE.

PLATE I.
TRANS. AM. SOC. CIV. ENGR'S.
VOL. XVI, NO. 349.
MACDONALD ON
TESTING MACHINE



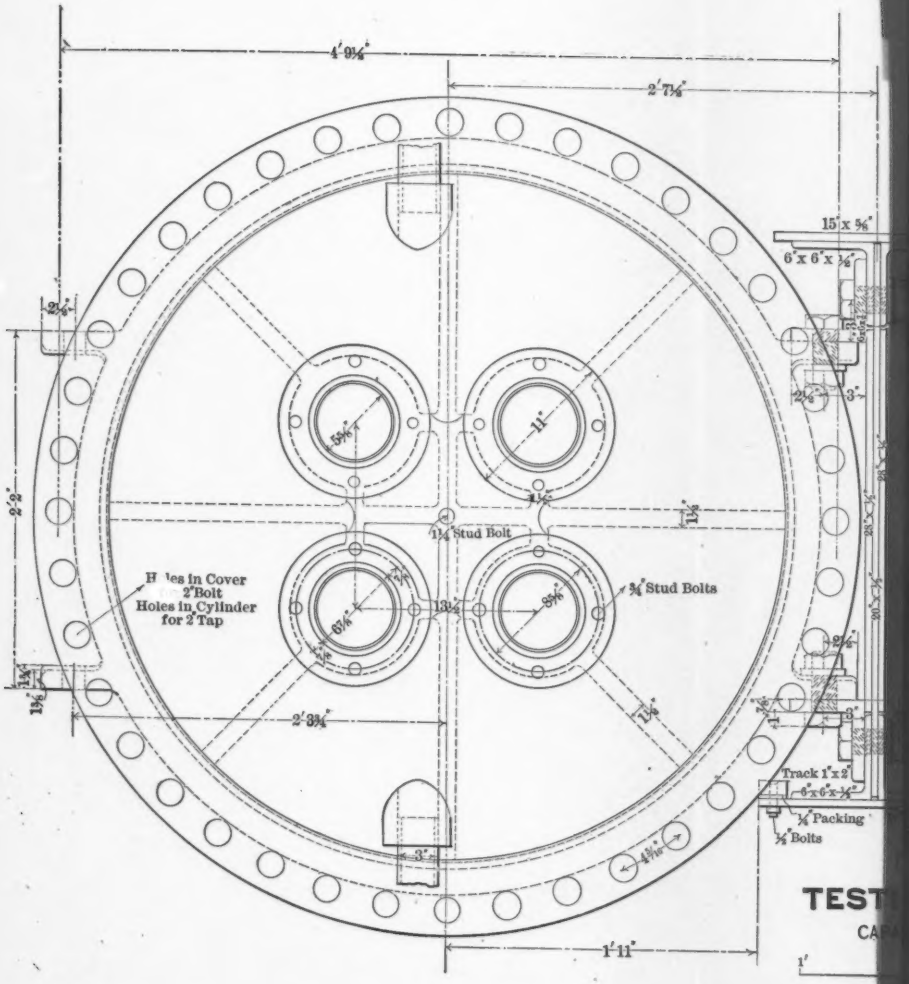
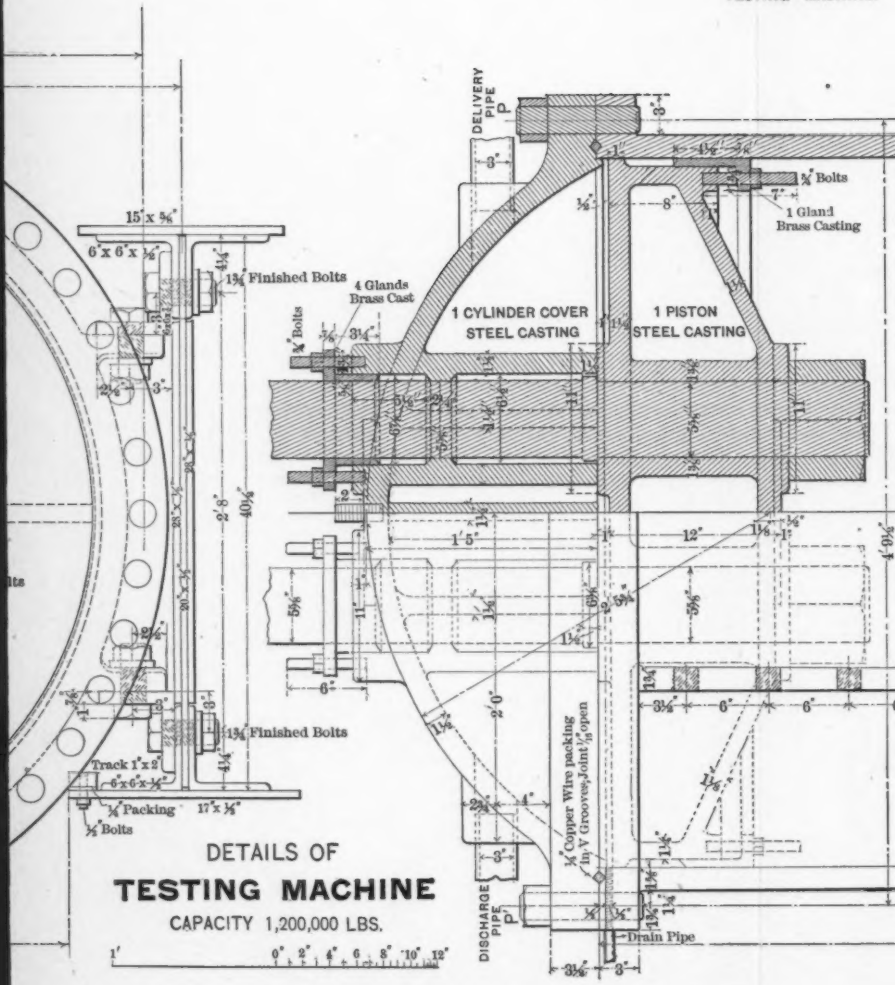

4' 9½"
2' 7½"
15" x ⅝"
6" x 6" x ½"
2½"
2' 2"
1¼" Stud Bolt
¾" Stud Bolts
Holes in Cover
2" Bolt
Holes in Cylinder
for 2" Tap
2' 3¾"
1' 11"
Track 1" x 2"
6" x 6" x ½"
¼" Packing
½" Bolts
TEST
CA

PLATE II.
TRANS. AM. SOC. CIV. ENGR
VOL. XVI, NO. 349.
MACDONALD ON
TESTING MACHINE.



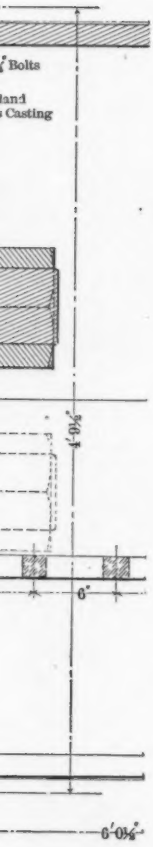
DETAILS OF

TESTING MACHINE

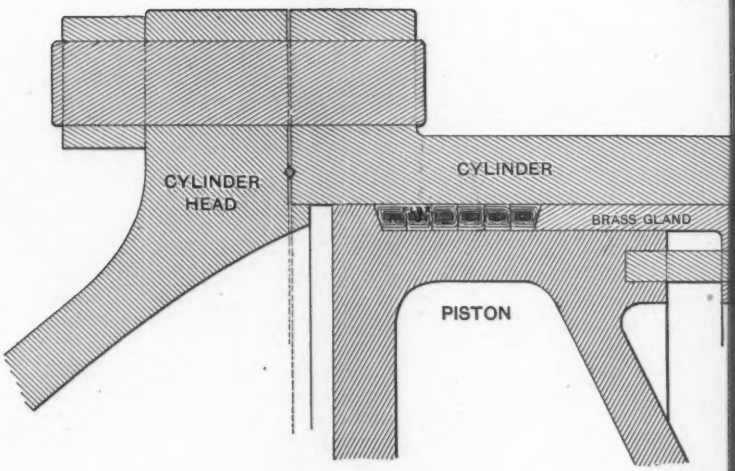
CAPACITY 1,200,000 LBS.

1' 0" 2" 4" 6" 8" 10" 12"

E II.
. CIV. ENGR'S.
NO. 349.
ALD ON
MACHINE.



PL
TRANS. AM. S
VOL. X
MACD
TESTIN



1,200,000 LBS. TESTING MACHINE

SECTION SHOWING PACKING OF PISTON.

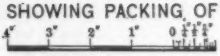


PLATE II.
M. SOC. CIV. ENGR'S.
. XVI, NO. 349.
ACDONALD ON
TING MACHINE.

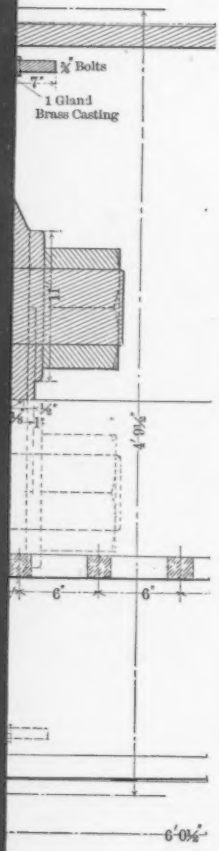
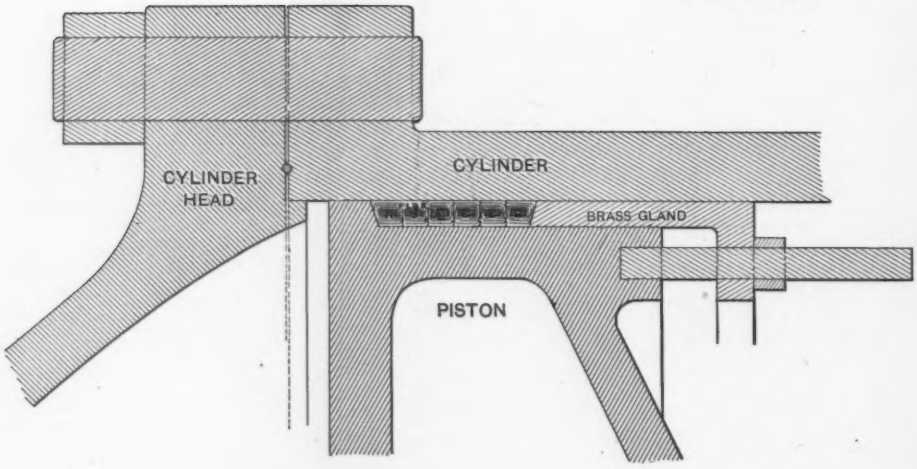
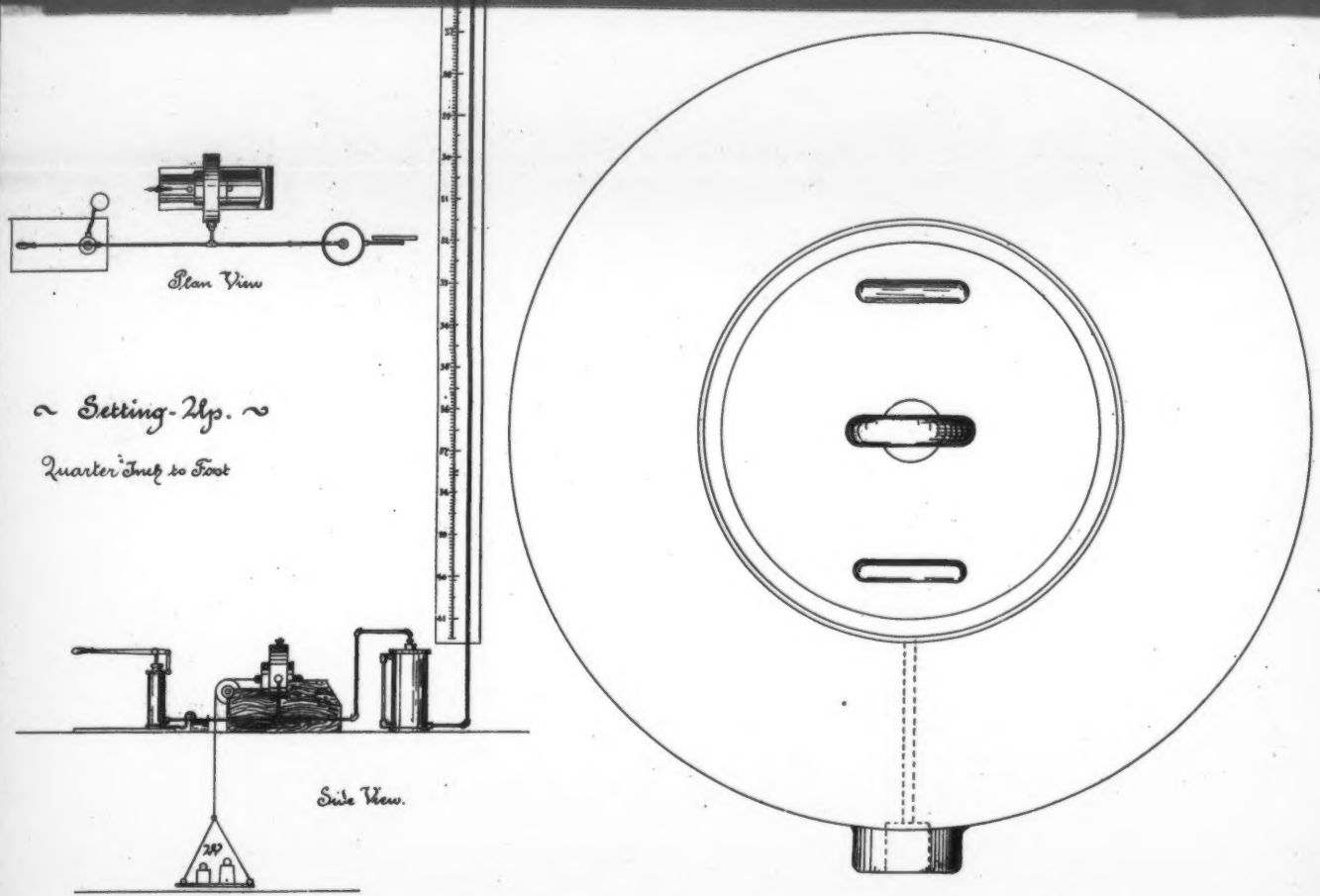


PLATE III.
TRANS. AM. SOC. CIV. ENGR'S.
VOL. XVI, NO. 349.
MACDONALD ON
TESTING MACHINE



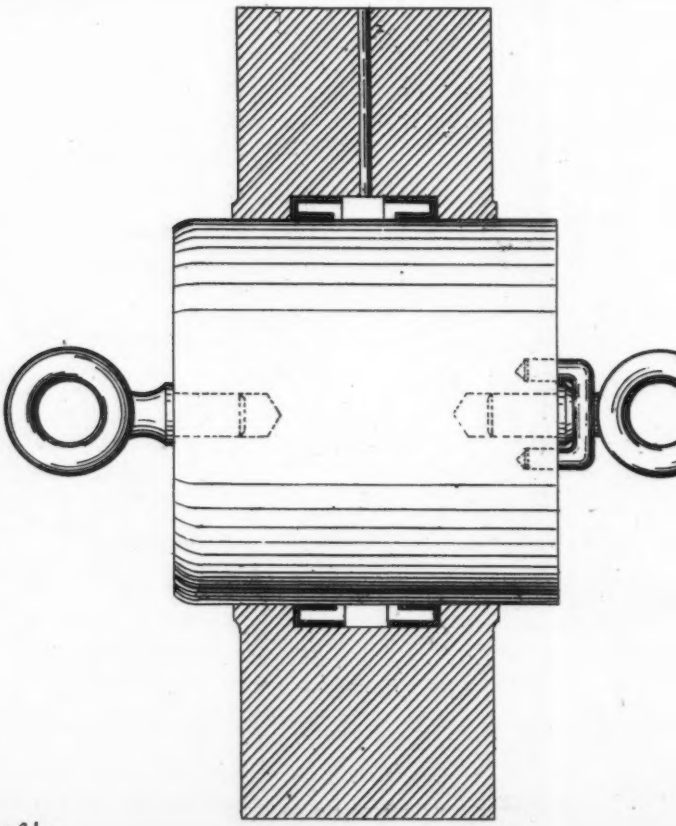
1,200,000 LBS. TESTING MACHINE

SECTION SHOWING PACKING OF PISTON.


Plan View
Setting-Up.
Quarter Inch to Foot
Side View.
Quart
View

Ill., and Saint Louis Bridge

Apparatus for Testing the Friction of H

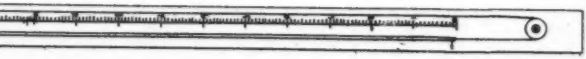


Quarter full Size

Section.

ridge Company
of Hydraulic Packing.

PLATE IV.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XVI NO. 349
COOPER ON
FRICTION OF PACKING



Variations of Packing. Half Size.